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**TECHNICAL MEMORANDUM 89/207**  
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**MODIFICATION OF THE GERIN FALLING  
BALL VISCOSITY COMPARATOR MODEL V3  
FOR USE AT THE STANDARD TEST  
TEMPERATURE OF 100°C**

R.D. Haggett - J.R. Matthews - D.E. Veinot

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TEST TEMPERATURE OF 100°C**

**R.D. Haggett - J.R. Matthews - D.E. Veinot**

**March 1989**

Approved by L.J. Leggat  
Director/Technical Division

Distribution Approved by

  
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# ABSTRACT

This report describes a modification to the Gerin Falling Ball Viscosity Comparator Model V3 for use at the standard test temperature of 100°C, which has been developed and tested at DREA Dockyard Laboratory. The Modified Falling Ball Viscosity Comparator when used at 100°C can accurately determine a percent change in the viscosity of a used MIL-L-9000G diesel lubricating oil compared to new oil of the same specification, regardless of the batch and/or manufacturer. This viscosity change can be determined onboard ship and used as a go/no-go indicator of the suitability for further service of a diesel lubricating oil. When used with fuel diluted solutions of known concentration the Modified Falling Ball Viscosity Comparator can be used to quantitatively determine the percentage fuel dilution in used diesel lubricating oil. TEST AND EVALUATION, CANADA, LUBRICATING OILS.

JES,



## SOMMAIRE

Le présent rapport décrit une version modifiée du viscosimètre comparateur à bille Gerin, modèle V3, destinée aux essais standard à une température de 100°C, qui a été mise au point et à l'essai au Laboratoire de l'arsenal du CRDA. Lorsqu'utilisée à 100°C, la version modifiée du viscosimètre comparateur à bille peut mesurer un changement en pourcentage de viscosité d'une huile de graissage pour diesels MIL-L-9000G usée par rapport à la même huile neuve, sans égard au lot ou au fabricant. Ce changement de viscosité peut être utilisée à bord d'un navire pour indiquer si une huile de graissage pour diesels est encore ou n'est plus utilisable. La version modifiée du viscosimètre comparateur à bille permet de mesurer le pourcentage de dilution par un carburant dans une solution d'huile de graissage pour diesels usée de concentration connue.

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# LIST OF SYMBOLS AND ABBREVIATIONS

A	surface area
ASTM	American Society for Testing and Materials
CF	Canadian Forces
CGSB	Canadian General Standards Board
cm	centimeter
cSt	centistoke
°C	degrees celcius
d	density
DREA	Defence Research Establishment (Atlantic)
F	force
FBVC	Falling Ball Viscosity Comparator
g	gravitational force
h	distance
in	inch
L	length
L <sub>eff</sub>	effective length
m	mass
MFBVC	Modified Falling Ball Viscosity Comparator
%	percent
p	pressure
ΔP	change in pressure
r	radius
$\tau$	shear stress
t	time
v	velocity
$\bar{v}$	average velocity
$\mu$	viscosity
VI	viscosity index
wt	weight

## 1.0 INTRODUCTION

The Falling Ball Viscosity Comparator (FBVC) Model V3 which is part of the Gerin DCA 300J Oil Condition Test Kit was brought into service onboard CF ships in 1987. The FBVC determines a percent difference, at room temperature, between the viscosity of a used oil and the same oil when new<sup>1</sup>. Test results obtained onboard one ship indicated high fuel dilution in the MIL-L-9000G diesel lubricating oils of several diesel engines when compared to a new oil standard. Based on these results oil changes were carried out. Subsequent tests on the freshly changed oils continued to indicate high fuel dilution resulting in further oil changes with the associated material and labour expenses. Because the ship's staff were suspicious of the results obtained using the FBVC, samples of the oils were submitted to DREA Dockyard Laboratory for analysis.

The kinematic viscosities of all samples were determined at 100°C and 40°C using the ASTM test method, D445-82<sup>2</sup>. The viscosities of the oils at 100°C were within the acceptable range of 11.4 to 14.1 centistokes (cSt) for MIL-L-9000G<sup>3</sup> and indicated no fuel dilution. The samples were also analysed by the laboratory using an identical Gerin DCA 300J test kit and results confirmed those obtained by the ship. Because the FBVC is used at room temperature, the viscosities of the oils at this temperature were determined by extrapolation of the viscosity results obtained at 100°C and 40°C using the ASTM Standard Viscosity-Temperature Chart (D341)<sup>4</sup>. When the room temperature viscosities of the new oil standard and the used oils were compared, the percentage differences in the viscosities were approximately the same as those obtained using the FBVC. Further investigation showed that the new oil used as a standard by the ship was not of the same batch number as the oil in service. Oils of the same grade (MIL-L-9000G) and from different suppliers or from the same supplier but from different batches may have similar viscosities at 100°C, the standard test temperature, but considerably different viscosities at room temperature, the temperature at which the Gerin FBVC is used. The difference in the room temperature viscosities of two oils,

of the same specification but from different batches, is due to variations in the properties of the crude oil from which they are derived and the method and degree of refining. This is reflected in the viscosity indexes of the two oils. The viscosity index of an oil is an empirical number which indicates the effect of change in temperature on the viscosity of the oil<sup>5</sup> and may vary with batch number. A high viscosity index denotes a low rate of change in viscosity with temperature while a low viscosity index indicates the converse. The purchase specification for MIL-L-9000G does not stipulate a viscosity index, but rather a range for viscosity at 100°C.

The use of a new oil standard from a different batch than the oil under test can lead to erroneous results when the new and used oils are compared at room temperature using the FBVC. This problem can be alleviated by using a new oil standard that is from the same batch as the used oil under test when comparing viscosities at room temperature. However, because purchase, storage and supply procedures do not segregate oils from different sources, CF ships have difficulty ensuring that only oils of one batch are carried onboard.

In this report a simple and inexpensive modification to the Gerin DCA 300 FBVC Model V3 is described. This modification allows the percent viscosity change of used MIL-L-9000G oils to be measured at the standard test temperature of 100°C.

## 2.0 EQUIPMENT

### 2.1 Gerin DCA 300 Falling Ball Viscosity Comparator Model V3

The FBVC, shown diagrammatically in Figure 1, consists of a 7.6 cm (3 in) wide by 25.4 cm (10 in) high by 4.8 mm (3/16 in) thick aluminum back plate incorporating three stainless steel falling ball/rod assemblies, a rod release mechanism and a three tube fold-out tube rack. A fold-out aluminum easel is attached to the bottom of the back plate. When folded down, the easel stands the instrument at a 12° angle to the vertical which provides constant and equal friction on each of the three rods.

The FBVC is designed to compare the room temperature viscosity of a used oil with that of a new reference oil. A ball/rod assembly falls through a new MIL-L-9000G diesel lubricating oil, which can have a viscosity ranging between 250 cSt. and 450 cSt. at room temperature, depending on the batch, in 30-45 seconds. Any change in viscosity caused by fuel dilution, the addition of a make-up oil, oxidation, dead filter, excessive carbon blow-by or coolant leakage will affect the rate of fall of the ball through the oil and is recorded on the instrument as a percent (%) change in viscosity.

## 2.2 Fluid Mechanics Principle of the Falling Ball Viscosity Comparator

The viscosity of a fluid is defined as the resistance to flow of one layer of a fluid over another<sup>6</sup>. Viscosity may also be thought of as the internal friction of the fluid. According to Stoke's law<sup>7</sup>, a ball falling freely under the action of gravity through a viscous fluid in a vessel of infinite diameter will acquire a constant velocity (v):

$$v = \frac{2gr^2(d_1 - d_2)}{9\mu} \quad (1)$$

where g is the gravitational force, r is the radius of the sphere,  $d_1$  and  $d_2$  are the densities of the sphere and the fluid respectively, and  $\mu$  is the viscosity of the fluid.

It can be seen from this equation that the velocity of a falling ball will vary with a change in the density of the ball or the fluid, the radius of the ball and the viscosity of the fluid. This relationship is true for a ball falling through a liquid in a vessel of infinite diameter, but is not applicable when the vessel has a finite diameter; i.e., the diameter of the ball approaches the inside diameter of the vessel, due to the shear forces of the fluid as it passes between the ball and the cylinder wall<sup>8</sup>.

To demonstrate the effects of these shear forces, consider the apparatus

shown in Figure 2 which represents a classical viscometer. A cylinder of length (L) and radius (r) is suspended in a fluid filled tube with a clearance (h) between the cylinder and the tube wall. If a weight (wt) attached to a string wound around the circumference of the cylinder is allowed to fall, the cylinder will spin and achieve a tangential velocity ( $v_1$ ) equal to the velocity ( $v_2$ ) of the falling weight. The velocity of the falling weight is inversely proportional to the viscosity of the fluid in the tube. Newton's law of viscosity states:

$$\mathcal{T} = \mu \frac{du}{dy} \quad (2)$$

where  $\mathcal{T}$  is the shear stress and  $du/dy$  is the tangential deformation for one dimensional flow of a fluid. For the classical viscometer this may be reduced to:

$$wt = \mu \frac{A \cdot v_1}{h} \quad (3)$$

where  $\mu$  is the viscosity of the fluid and A is the surface area of the cylinder wall. Solving for  $\mu$  yields:

$$\mu = \frac{wt \cdot h}{A \cdot v_1} \quad (4)$$

Although this apparatus can provide an accurate and absolute viscosity measurement, it is not practical for routine use.

When the FBVC (Figure 3) is used, the falling ball develops a fluid pressure in the tube beneath the ball and this pressure resists the downward force exerted by the mass (m) of the ball/rod assembly. This downward force, expressed as:

$$F_{\text{down}} = (m \cdot g - \text{buoyant force}) \cos 12^\circ - \mu_{\text{friction}} (m \cdot g - \text{buoyant force}) \sin 12^\circ \quad (5)$$

takes into account the  $12^\circ$  angle of inclination of the instrument as well as the frictional forces on the ball/rod assembly as it falls through the control mechanism at the top of the instrument. The last term, which accounts for the frictional forces on the ball/rod assembly, is very small and is the same for all the ball/rod assemblies used for the comparisons, and therefore does not need to be considered.

The pressure ( $p_1$ ) of the fluid below the ball is equal to the downward force ( $F$ ) of the ball divided by the cross sectional area of the tube, where  $r_2$  is the inside radius of the tube. Because the radius of the ball remains constant,  $p_1$  is inversely proportional to the cross sectional area of the tube and can be expressed as:

$$p_1 = \frac{F}{\pi r_2^2} \quad (6)$$

As the ball falls, fluid is displaced and forced to flow upward between the ball and the tube wall. The velocity ( $v_2$ ) of the fluid flowing between the ball and the tube wall is proportionately greater than the velocity of the falling ball. Thus the ball can be considered to remain stationary as the fluid flows around it. If the ball is considered to remain stationary the fluid below the ball will, in addition to having a pressure ( $p_1$ ), acquire a relative velocity ( $v_1$ ). Because the velocity of the fluid flowing through the gap between the ball with radius ( $r_1$ ), and the tube wall with radius  $r_2$ , is proportional to the the velocity of the falling ball/rod assembly, the average velocity ( $\bar{v}$ ) of the fluid flowing around the ball may be determined as follows:

$$\bar{v} = \frac{\pi r_2^2 \cdot v_1}{\pi(r_2^2 - r_1^2)} \quad (7)$$

Bernoulli's theorem, expressed in equation (8), states that at any point in a tube through which a fluid is flowing, the sum of the pressure, potential energy and kinetic energy is constant. This theorem can be used to express the relationship of the pressure ( $p_1$ ) of the fluid below the ball to the pressure ( $p_2$ ) of the fluid at any location along the gap. If  $y_1$  and  $y_2$  are the elevations in the fluid above a reference point at which the measurements are taken,  $d$  is the density of the fluid and  $v_1$  and  $v_2$  are the velocities of the fluid below the ball and at any location of interest along the gap respectively, then:

$$p_1 + dgy_1 + 1/2dv_1^2 = p_2 + dgy_2 + 1/2dv_2^2 \quad (8)$$

For this analysis it must be assumed that an effective length ( $L_{eff}$ ) exists along which the velocity is constant at  $v$  and the driving pressure is  $p_2$ . Outside this effective length shear forces are assumed not to exist and so the effective driving pressure  $p_2$  is considered to be approximately equal to  $p_1$ :

$$p_1 = p_2 \quad (9)$$

Because the pressure ( $p_3$ ) of the fluid above the ball after it passes through the gap between the ball and the tube wall becomes negligible,  $p_2$  is also equal to the change in pressure ( $\Delta P$ ) across the narrow gap.

$$\Delta P = p_2 - p_3 = p_2 \quad (10)$$

To determine the velocity profile, shown in Figure 4, of the fluid in the narrow gap between the ball and the tube wall, the driving forces which cause the fluid to flow through the gap must be equated to the viscous forces opposing this flow. Figure 4 shows a three dimensional section of this gap taken where the distance (h) between the ball circumference and the inside tube wall is minimum. Therefore (h) is equal to the difference between the inside radius of the tube and the radius of the ball:

$$h = r_2 - r_1 \quad (11)$$

The effective length ( $L_{eff}$ ) is the length of the segment on the circumference of the ball, along the fall line, where the shear force is most significant and over which the gap can be considered constant at h. The force driving the fluid through the gap is the pressure ( $p_2$ ) applied to the bottom area of the shaded element ( $2x$  in Figure 4) around the entire orthogonal circumference of the ball and can be expressed as:

$$p_2 = \Delta P \cdot 2x \cdot 2\pi \frac{(r_2 + r_1)}{2} \quad (12)$$

The viscous force opposes the driving force and acts on the two surfaces an equal distance (x) from the centre of flow at  $x=0$ . The effective area over which the viscous force acts is the effective length, ( $L_{eff}$ ), multiplied by the average circumference at the two surfaces at  $\pm x$  from the centre of flow (Figure 4). This viscous force may be expressed as:

$$\text{Viscous force} = \mu \cdot A_{\text{surface}} \frac{dv}{dx} \quad (13)$$

$$= \mu \cdot 2L_{eff} \cdot 2\pi \frac{(r_2 + r_1)}{2} \frac{dv}{dx} \quad (14)$$

When Equations 12 and 14 are equated and integrated from  $x=x$  to  $h/2$  and  $v=v$  to 0 and noting that the forces are in opposite directions then:

$$\int_x^{h/2} \frac{\Delta P \cdot x}{\mu \cdot L_{eff}} dx = - \int_v^0 dv \quad (15)$$

and this reduces to:

$$v = \frac{\Delta P}{2\mu \cdot L_{eff}} \left( (h/2)^2 - x^2 \right) \quad (16)$$

The maximum velocity ( $v_{max}$ ) in the gap can be found by setting  $x$  equal to 0, therefore:

$$v_{max} = \frac{\Delta P}{2\mu \cdot L_{eff}} \cdot \frac{h^2}{4} \quad (17)$$

and the average velocity ( $\bar{v}$ ) in the gap can be found by integrating Equation 16 from 0 to  $h/2$  and is:

$$\bar{v} = \frac{\Delta P}{2\mu \cdot L_{eff}} \cdot \frac{2}{h} \int_0^{h/2} ((h/2)^2 - x^2) dx \quad (18)$$

After integrating Equation 18, it can be seen that the average velocity of the fluid in the gap between the ball and the tube wall is dependent on the change in pressure, the square of the gap width, the viscosity of the fluid and the effective length of the ball and can be expressed as:

$$\bar{v} = \frac{\Delta P}{2\mu \cdot L_{eff}} \cdot \frac{h^2}{6} \quad (19)$$

By combining Equations 19, 7 and 6 a value for the velocity ( $v_1$ ) of the fluid in the tube below the ball can be calculated and is:

$$v_1 = \frac{(m \cdot g - \text{buoyant force}) \cos 12^\circ (r_2^2 - r_1^2)}{12\pi r_2^4} \cdot \frac{h^2}{\mu \cdot L_{eff}} \quad (20)$$

When the ball/rod assembly falls through the fluid, the buoyant force will increase as more of the rod enters the tube and displaces fluid. Because the buoyant force changes as the ball/rod assembly falls, Equation 20 will never reduce trivially. Equation 20 can be used to establish a relationship between the velocity of the falling ball/rod assembly and the viscosity of the fluid when using the Modified Falling Ball Viscosity Comparator (MFBVC) at 100°C. It can be seen from this equation that the velocity of the balls varies inversely with the viscosity of the fluids. When any two oils, for example oils a and b, with different viscosities are tested and the fall times of the balls are recorded in seconds, application of Equation 20 to both oils will result in the approximately proportional relationship:

$$\frac{v_{1a}}{v_{1b}} = \frac{\mu_b}{\mu_a} \quad (21)$$

The velocity of a falling ball/rod assembly is the distance the ball falls divided by the time it takes for the ball to fall that distance. For a constant fall distance the ratio of the fall times will then be approximately equal to the ratio of the viscosities:

$$\frac{t_b}{t_a} = \frac{\mu_b}{\mu_a} \quad (22)$$

where  $t$  is the fall time in seconds. Therefore, by comparing a new sample of MIL-L-9000G and a series of fuel diluted standards and recording the difference in fall times as percent difference in viscosity, a relationship can be established between the level of fuel dilution and the percent viscosity difference of the oils.

### 2.3 Modification of the Gerin Falling Ball Viscosity Comparator Model V3 for Use at 100°C

The relationship between the mass, diameter and velocity of the falling ball/rod assembly is expressed in Equation 20. The velocity of the ball/rod assembly can be determined by using this equation with a standard oil of known viscosity at 100°C. By reducing the mass and/or increasing the radius of the ball, the velocity of the ball/rod assembly can be reduced to an easily measured rate.

At 100°C the stainless steel balls used with the FBVC have a fall time of less than one second through new MIL-L-9000G as compared to a fall time of 30 to 45 seconds at room temperature. This is due to the reduction in the viscosity of the new oil to approximately 13.5 cSt at 100°C from approximately 500 cSt at room temperature. Replacement of the stainless steel balls supplied with the instrument with aluminum balls of the same radius results in a reduction in the mass of each ball/rod assembly from 11.49 grams to 7.14 grams. This decrease in the mass of the ball/rod assembly increased the fall time to approximately 2.9 seconds. If aluminum balls with a larger radius are used the volume of fluid flow around the ball decreases owing to the reduced clearance between the ball and the inside tube wall to 0.127 mm (0.005 in) from 0.397 mm (0.0156 in). This modification produced a fall time for the aluminum balls through a new MIL-L-9000G oil at 100°C of approximately 23 seconds. The fall times of the individual ball/rod assemblies can be adjusted to within 0.02 seconds of each other by polishing with one micron diamond paste polishing compound.

Laboratory results have shown that the viscosities of two samples of new MIL-L-9000G from different batches can vary by as much as 40% at room temperature due to the different viscosity indexes of the two oils. To enable viscosity comparisons at the standard test temperature of 100°C, the following modifications, shown diagrammatically in Figure 5, were made to the FBVC. These modifications are in addition to the modifications made to the falling balls. To achieve the 100°C test temperature, the instrument was placed in a covered bath containing fresh water which was heated to boiling with a standard single element laboratory hot plate. Water boils at 100°C at standard atmospheric pressure (760mm Hg), and the boiling point does not vary significantly with normal fluctuations in sea level atmospheric pressure.

The bath cover was cut out to allow the instrument, with the fold out easel removed, to be placed on a rack in the boiling water. The rack was canted at a 12° angle to the vertical to provide constant and equal friction on each of the three rods. The cut out in the cover was surrounded on the underside by a stainless steel dam to act as a seal to prevent steam from escaping and condensing on the instrument. Two 16.9 mm (5/8 in) diameter holes in the front portion of the cover allowed additional oil-filled sample tubes to be suspended in the boiling water and warmed to test temperature.

To facilitate handling at 100°C, a 6.4 mm (1/4 in) thick Dupont Delrin™ backing plate was added to insulate the top 7.6 cm (3 in) of the aluminum instrument from the 100°C water bath. The Delrin™ plate extends 13 mm (1/2 in) past the aluminum back plate on the top and sides. The control buttons for the rod release mechanism were insulated with Delrin™ caps which were press fitted and epoxied into place.

### 3.0 EXPERIMENTAL METHOD

#### 3.1 Preparation of Standards

The MIL-L-9000G diesel lubricating oils used for this work were manufactured by two different suppliers. The batch numbers were: Esso Batch

Number 1-1-87, Castrol Batch Numbers 23-6-87 and 24-9-87. The diesel fuel used for the preparation of the fuel diluted standards was Canadian General Standards Board (CGSB) specification 3-GP-11Ma naval distillate fuel<sup>9</sup>. Standard solutions of the different batches of new MIL-L-9000G diesel lubricating oil containing 1, 3, 5, and 7% (weight/weight) 3-GP-11Ma fuel were prepared and viscosity comparisons were made using the MFBVC at 100°C.

### 3.2 Procedure

A detailed stepwise description of the procedure used to compare the viscosities of samples using the MFBVC at 100°C is given in Appendix A.

## 4.0 DISCUSSION

### 4.1 Kinematic Viscosity and Viscosity Index Determination of Three New MIL-L-9000G Diesel Lubricating Oils

The Kinematic viscosities of the three new MIL-L-9000G diesel lubricating oils, batch numbers Esso 1-1-87 and Castrol 23-6-87 and 24-9-87, were determined at 100°C and 40°C by ASTM method D445-82 and are shown in Table 1. The room temperature (20°C) viscosities of these oils are also shown in Table 1 and were determined using the ASTM Viscosity-Temperature Charts for Liquid Petroleum Products (D341), Chart VII as shown in Figure 6. The Viscosity Index, (VI), of each new oil was calculated using ASTM method D2270-86<sup>10</sup> and are shown in Table 1. These results indicate that the variation in the viscosities of the new oils at room temperature was significant (500 cSt to 800 cSt) while the variation in the viscosities at 100°C was very small (13.0 cSt to 13.6 cSt).

#### 4.2 Comparison of Three New MIL-L-9000G Diesel Lubricating Oils at 100°C Using the Modified Falling Ball Viscosity Comparator

Three samples of new MIL-L-9000G diesel lubricating oils from different batches were compared at 100°C using the MFBVC. Table 2 shows this comparison in terms of the fall times of the balls between the start line and 100% line on the comparator. The results show that the average fall time of the balls was 22.84 seconds  $\pm$  0.20 seconds.

#### 4.3 Variation in Percent Viscosity Difference at 100°C of Fuel Diluted Samples

Standard solutions of the new MIL-L-9000G diesel lubricating oils containing 1, 3, 5 and 7% (weight/weight) 3-GP-11Ma naval distillate fuel were tested at 100°C using the MFBVC. The percent viscosity differences taken directly from the scale on the viscosity comparator between the diluted oils and the new undiluted oils are shown in Table 3. The results in Table 3 show that the percent viscosity difference of the fuel diluted samples does not vary significantly from batch to batch at 100°C at dilutions of 3% and above.

#### 4.4 Percent Viscosity Difference Between New MIL-L-9000G Diesel Lubricating Oils and 5% Fuel Diluted Samples at 100°C

Five percent (weight/weight) fuel diluted samples prepared from each new MIL-L-9000G diesel lubricating oil were used to determine the variation in percent viscosity difference when the dilution from one batch was tested against a new oil of a different batch. The results of these tests are shown in Table 4 and show that when each of the 5% solutions was tested against each of the new oils the percent viscosity difference range was 15% to 17%. These results indicate that, regardless of the batch, a 5% fuel dilution gives approximately 16% viscosity difference and therefore the percent viscosity decrease at 100°C can be used to monitor percent fuel dilution without the

problems encountered at room temperature due to differing viscosity indexes.

## 5.0 CONCLUSIONS

A modification to the Gerin FBVC Model V3 for use at the standard test temperature of 100°C has been developed and tested at DREA Dockyard Laboratory. The MFBVC when used at 100°C can accurately determine a percent change in the viscosity of a used MIL-L-9000G diesel lubricating oil compared to new oil of the same specification, regardless of the batch and/or manufacturer. This viscosity change can be used onboard ship as a go/no-go indicator of the suitability for further service of a diesel lubricating oil. When used with fuel diluted solutions of known concentration the MFBVC can be used to quantitatively determine the percentage fuel dilution in used diesel lubricating oil

TABLE 1

Kinematic Viscosity at 20°C, 40°C and 100°C and the Calculated Viscosity Index  
of Three New MIL-L-9000G Diesel Lubricating Oils

<u>SUPPLIER</u>	<u>BATCH NUMBER</u>	<u>KINEMATIC VISCOSITY (cSt)</u>			<u>VISCOSITY INDEX (VI)</u>
		<u>20°C</u>	<u>40°C</u>	<u>100°C</u>	<u>ASTM D2270-86</u> <u>(D341)</u>
ESSO	1-1-87	500	138.9	13.6	92.5
CASTROL	23-6-87	800	174.1	13.1	54.3
CASTROL	24-9-87	700	168.8	13.0	57.2

TABLE 2

Viscosity Comparison at 100°C of Three New MIL-L-9000G Diesel Lubricating Oils

<u>SUPPLIER</u>	<u>BATCH NUMBER</u>	<u>MEAN FALL TIME (SECONDS)</u>	<u>STANDARD DEVIATION</u>
ESSO	1-1-87	23.03	± 0.096
CASTROL	23-6-87	22.85	± 0.033
CASTROL	24-9-87	22.64	± 0.154

TABLE 3

Variation in Percent Viscosity Difference at 100°C of Fuel Diluted Samples

<u>SUPPLIER</u>		<u>MEAN FALL TIME</u>	<u>VISCOSITY</u>
<u>AND BATCH #</u>	<u>FUEL DILUTION (%)</u>	<u>(SECONDS)</u>	<u>DIFFERENCE (%)</u>
ESSO 1-1-87	0.0	23.03	0
	1.0	21.45	4
	3.0	21.07	7
	5.0	18.93	15
	7.0	18.55	18
CASTROL 23-6-87	0.0	22.85	0
	1.0	21.52	3
	3.0	20.83	7
	5.0	18.35	19
	7.0	18.01	19
CASTROL 24-9-87	0.0	22.64	0
	1.0	21.69	2
	3.0	20.94	6
	5.0	18.26	16
	7.0	17.91	19

TABLE 4

Percent Viscosity Difference at 100°C Between New MIL-L-9000G  
Diesel Lubricating Oils and 5% Fuel Diluted Samples

NEW OIL SUPPLIER AND BATCH NUMBER	PERCENT VISCOSITY DIFFERENCE FOR 5% FUEL DILUTION		
	<u>BATCH #1-1-87</u>	<u>BATCH # 23-6-87</u>	<u>BATCH # 24-9-87</u>
ESSO 1-1-87	16	15	17
CASTROL 23-6-87	16	15	17
CASTROL 24-9-87	16	16	15

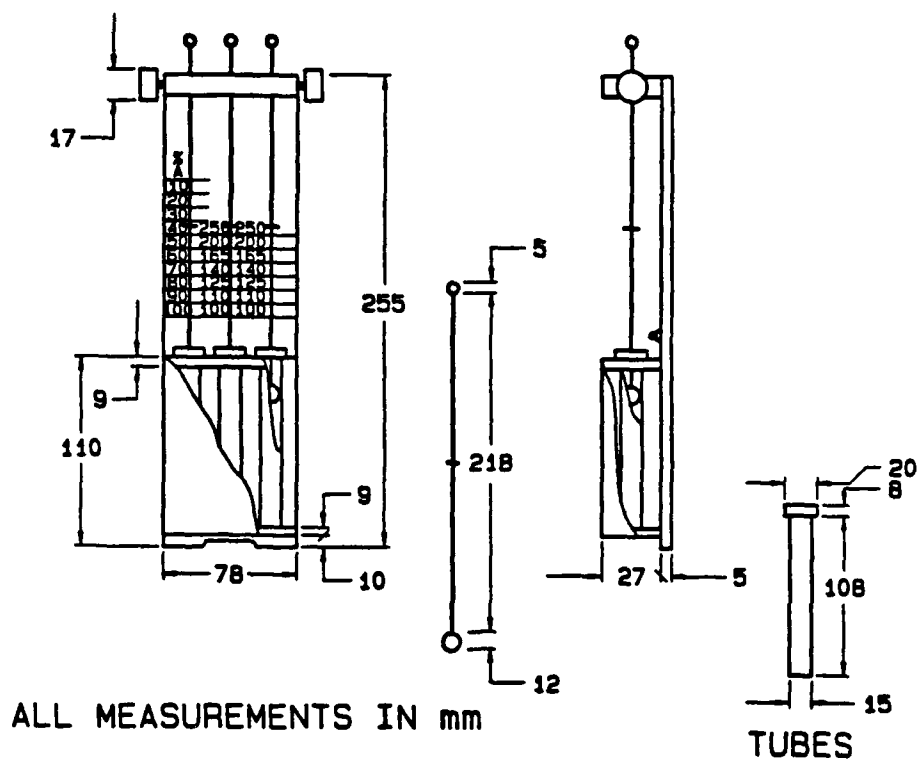


FIGURE 1. Gerin Falling Ball Viscosity Comparator Model V3.

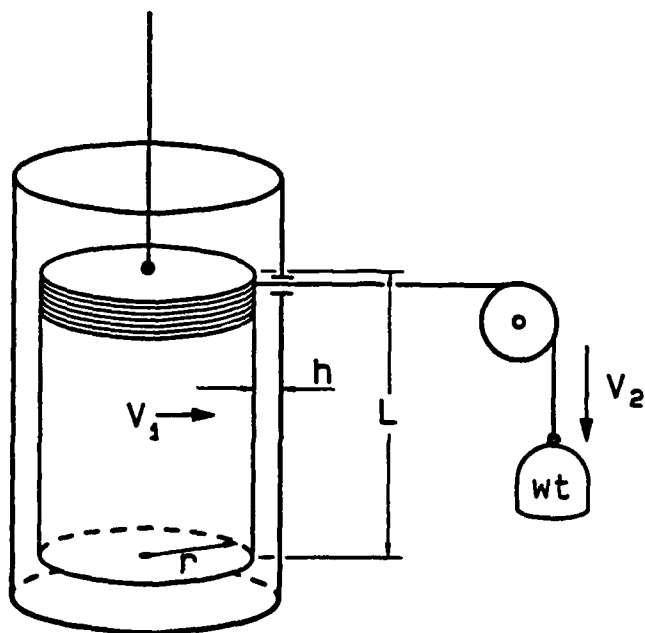


FIGURE 2. Classical apparatus for determining absolute viscosity of a fluid.

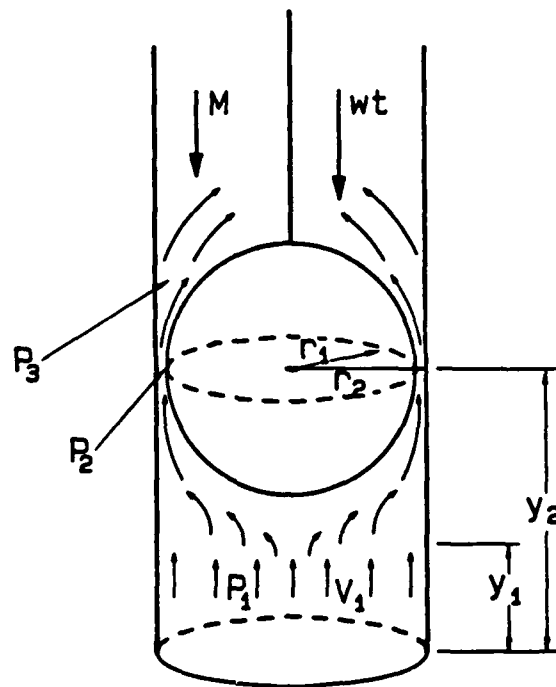


FIGURE 3. Fluid flow around a falling ball in a tube of finite diameter.

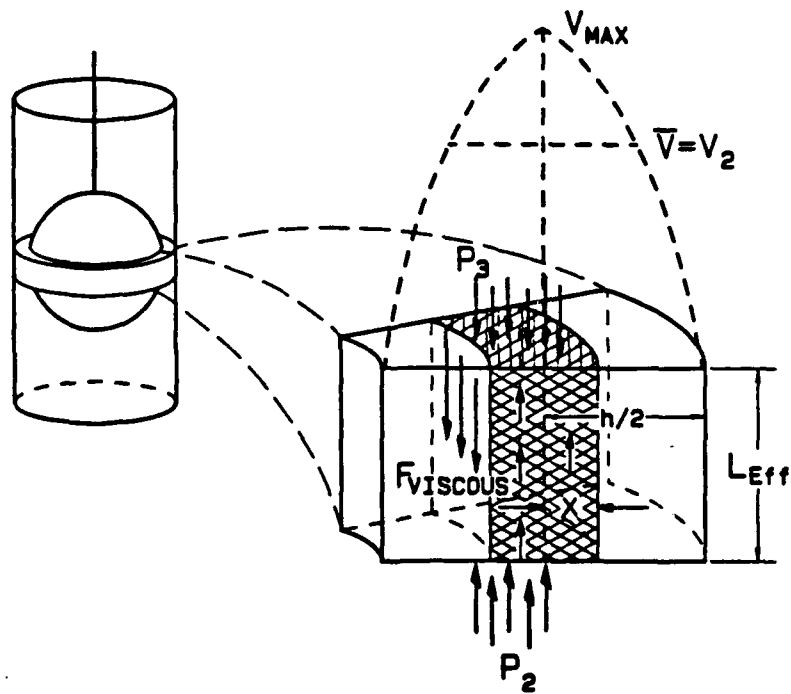


FIGURE 4. Velocity profile of fluid between a falling ball and tube wall.

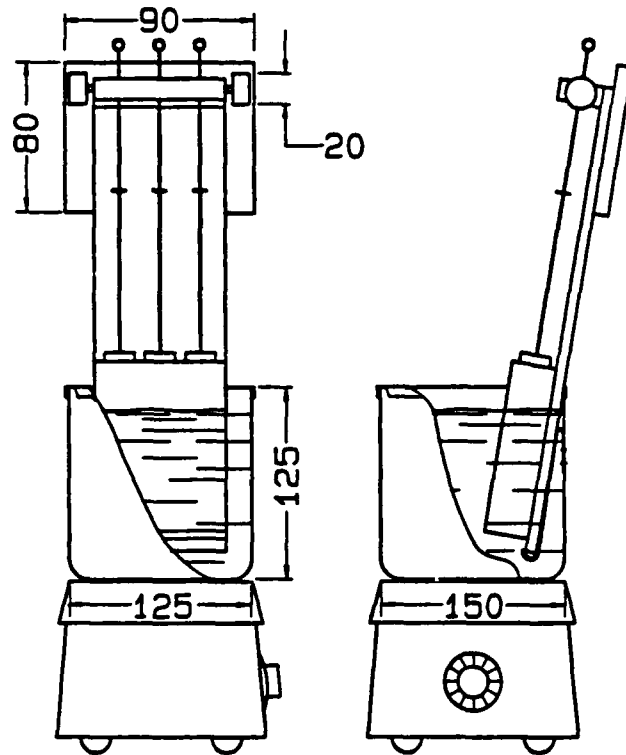


FIGURE 5. Modified Falling Ball Viscosity Comparator.

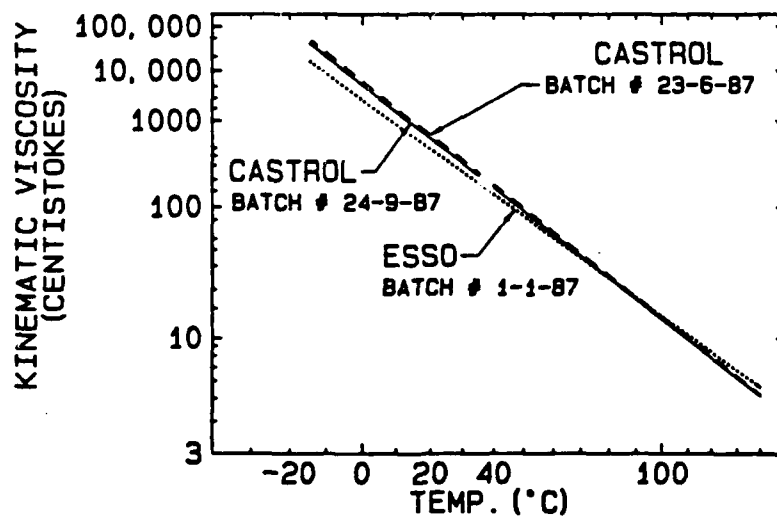


FIGURE 6. Extrapolated room temperature viscosities of three new MIL-L-9000G diesel lubricating oils.

## APPENDIX A

### MODIFIED FALLING BALL VISCOSITY COMPARATOR TEST PROCEDURE

Place the Modified Falling Ball Viscosity Comparator on the bench-top rack with the rods in the full up position. Pull the sample tube holder forward to facilitate insertion and removal of the sample tubes. The rods should be handled only by the brass balls on the top of each rod. Fill the sample tube marked "A" with a new oil to the brass shoulder, for use as a reference standard, and place it in the left-hand position of the tube holder marked "A" on the scale.

Fill the sample tubes marked "1" through "4" with the used oils to be tested. Record the origin of the used oil samples against the sample tubes in which they are contained. Place two of the filled sample tubes in positions "1" and "2" in the tube holder and return it to the "Test" position so that it rests against the comparator back plate. The remaining two sample tubes are placed in the holes in the water bath cover to heat to test temperature.

Place the Modified Falling Ball Viscosity Comparator, with the filled sample tubes in the sample holders, on the canted rack in the water bath. Turn the hot plate on and set the heat setting to the high position and allow 20 minutes for the water to come to a full boil and the sample tubes to heat to the test temperature. Do not allow the water bath to boil dry. If the water level drops below half full, refill the bath and repeat heating procedure. The water level will not drop below half full during normal operation, i.e. testing the four used oil samples, but the water level should be checked and the bath filled before each use.

The viscosity comparator is sensitive to friction on the rods, therefore, the rods should be cleaned before each test by wiping with a clean tissue.

Wipe any condensation off the bottom portion of the rods with a clean tissue, and push all three rods gently down into the filled sample tubes as

far as possible.

Push the left-hand reset button until a "click" is heard. This will reset the rod release mechanism to the "ready" position.

Pull the rods in position "A" and "1" up by the brass balls until the markers on each rod are at the "Start" line position on the scale.

Grasp the upper portion of the viscosity comparator by the insulated back plate using your right hand, placing the right thumb on the right hand rod release button. To take a reading, press in and hold the button allowing the two rods to fall through the oil samples. Release the button when the first rod marker reaches the 100% line on the scale. Each viscosity test should be run in duplicate to ensure repeatable results. Repeat the test procedure for the used oil in sample tube "2".

#### Interpretation of Results

If the "A" rod marker reaches the 100% line before the rod marker of the used oil being tested, the used oil is thicker and has an increased viscosity.

Example: New oil at 100% and used oil at 125% - the viscosity of the used oil is 25% greater than the new oil.

If the rod marker of the used oil being tested reaches 100% before rod marker "A" of the new oil, the used oil is thinner and has a decreased viscosity.

Example: Used oil at 100% and new oil at 80% - the used oil is 20% thinner than the new oil. This result does not mean the used oil has a fuel dilution of 20%, only that the viscosity is 20% less than the viscosity of the new oil. A 5% fuel diluted sample will have a viscosity that is approximately 16% less than the viscosity of the new oil.

**NOTE:** The engine oil should be replaced when the viscosity difference exceeds +/- 15% of the new oil.

Cleaning And Care Of The Modified Falling Ball Viscosity Comparator

The Modified Falling Ball Viscosity Comparator should be cared for and cleaned as outlined in the operating instructions included with the Gerin DCA 300 Oil Contamination Test Kit.

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This report describes a modification to the Gerin Falling Ball Viscosity Comparator Model V3 for use at the standard test temperature of 100°C which has been developed and tested at DREA/Dockyard Laboratory. The Modified Falling Ball Viscosity Comparator when used at 100°C can accurately determine a percent change in the viscosity of a used MIL-L-9000G diesel lubricating oil compared to new oil of the same specification, regardless of the batch and/or manufacturer. This viscosity change can be used onboard ship as a go/no-go indicator of the suitability for further service of a diesel lubricating oil. When used with fuel diluted solutions of known concentration, the Modified Falling Ball Viscosity Comparator can be used to quantitatively determine the percent fuel dilution in used diesel lubricating oil.

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